

Attempts at larval rearing of the endangered western European sturgeon, *Acipenser sturio* (Acipenseridae), in France

by

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ABSTRACT. - Preliminary results are reported of larval rearing of the critically endangered European Atlantic sturgeon, *Acipenser sturio* L. Two live food items (chironomids and *Artemia salina* nauplii) and two compound diets were compared as first feeding. As soon as nauplii were observed in the digestive tract, they were delivered to all batches in order to improve survival of the maximum number of individuals. Growth in the batch fed only nauplii was better until 23 days post hatching (dph). The survival figure for larvae subjected to a short weaning period (3 days) at 17.5°C reached a maximum of 34% survival recorded at 34 days post initiation of weaning in 55-dph larvae. A long weaning (3 weeks) vs a short weaning (3 days) for 50-dph fish over a 56-day experimental period at 17.5°C resulted in better growth (6.4 g vs 2.9 g, respectively) and better survival (32.5% vs 6% respectively). The enrichment of nauplii did not show any difference in either growth or survival during a three-week experimental period. 50-dph fish fed live or frozen chironomids at 17.5°C during a 40-day period exhibited similar final weight (2.88 g and 2.87 g) and survival (98% and 98.5%). 2,000 hatchlings, 5,000 (~1 g) and 2,000 (~6.5 g) fingerlings were stocked in rivers.

RÉSUMÉ. - Tentatives d'élevage de larves de l'esturgeon atlantique européen *Acipenser sturio* (Acipenseridae) en France.

Les premiers résultats de l'élevage de larves de l'esturgeon atlantique européen, *Acipenser sturio*, en danger critique de disparition, sont présentés. La première expérience a comparé 4 aliments dont deux proies vivantes (chironomes et nauplii d'*Artemia salina*) et deux formules composées comme premier aliment et ceci à deux températures, 17,5°C et 21°C. L'ontogénèse précoce à 17,5°C révèle l'expulsion du bouchon de mélanine 12 jours après éclosion (jae), la présence des premiers nauplii d'*Artemia salina* dans le tractus digestif 16 jae et les premières fèces 19 jae. Dès que les premiers nauplii furent observés dans le tractus digestif, ils ont été distribués à tous les lots afin de ne pas risquer un refus d'autres aliments et donc sauver le maximum d'individus. La croissance a été meilleure pour les lots nourris uniquement avec des nauplii jusqu'à 23 jae. Les poids à 37 jae étaient similaires, et les survies ont été significativement meilleures à 17,5°C par rapport à celles enregistrées à 21°C quel que soit le régime alimentaire (64-70% contre 50-53%). La seconde expérience traitait du sevrage. La courbe de survie des larves ayant été l'objet d'un sevrage court (3 jours) à 17,5°C montre un maximum de 34% 34 jours après le début du sevrage et pour des larves âgées de 55 jours lors du début du sevrage. Un sevrage long (3 semaines) comparé à un sevrage court (3 jours) à 17,5°C de larves âgées de 50 jours conduit 56 jours plus tard à une meilleure croissance (6,4 g contre 2,9 g, respectivement) et à une meilleure survie (32,5% contre 6%, respectivement). La troisième expérience a testé l'influence d'un enrichissement des nauplii durant une période de 3 semaines ; aucune différence de croissance ou de survie n'a été mise en évidence. La quatrième expérience sur l'alimentation a comparé les effets de chironomides vivants ou congelés à 17,5°C durant une période de 40 jours à partir de larves de 51 jae pesant en moyenne 660 mg. Les résultats finaux n'ont révélé aucune différence que se soit en poids (2,88 g contre 2,87 g) ou en survie (98 et 98,5%). Trois lots de poissons ont été stockés en nombre égal en Garonne et Dordogne, au total 2000 larves en juin, 5000 alevins d'un poids moyen de 1 g en août et 2000 de poids moyen de 6,5 g en octobre, les deux derniers ayant été marqués avec de l'oxytetracycline. Quelques animaux ont été conservés pour des essais de constitution d'un stock de géniteurs.

Key words. - Acipenseridae - *Acipenser sturio* - France - Larval rearing - Feeding - Growth - Survival.

The European Atlantic sturgeon (*Acipenser sturio*) is a highly endangered species with only a few specimens remaining in just a fraction of its previous distribution range. Although its occurrence is scattered, it is believed that the species still completes its biological cycle in France (Trouvery *et al.*, 1984; Lepage and Rochard, 1995; Williot *et al.*, 1997).

For several years, an experimental rearing program has been underway to eventually provide stocking material to support the dwindling wild population (Williot *et al.*, 1997). Due to the erratic wild spawnings that still occur, and alarming reproductive quality of wild spawners (Wil-

liot *et al.*, 2002), this culture program is becoming more important especially in the light of species conservation objectives. For stocking and species conservation, it is necessary not only to increase the number of individuals in a broodstock in order to produce sufficient fingerlings but also to be able to rely on a large supplementary gene pool representing the natural population as closely as possible. The two spawnings performed in 1981 and 1985 were unsuccessful in obtaining satisfactory larval rearing. In 1995, we obtained some larvae with which we were able to carry out some experiments (Williot *et al.*, 2000). The

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objectives of the present work were as follows: 1- to determine the best rearing conditions with regard to growth and survival, 2- to determine the best feeding sequence, including weaning, and 3- to initiate stocking and retain specimens for experiments.

MATERIAL AND METHODS

Fish

23,000 larvae were obtained from spawning an adult pair of wild breeders caught incidentally in the Garonne River (female) and one week later in the upper part of the Gironde estuary (male) (Williot *et al.*, 2000). The limited number of larvae produced was mainly due to the poor physiological state of both breeders upon arrival. This was reinforced by the fact that it was difficult to efficiently sort all good quality larvae (those able to swim). This is because of the absence of positive phototaxis, as in the Siberian sturgeon (*Acipenser baerii*) and sterlet (*Acipenser ruthenus*) (Williot *et al.*, 2000). First feeding was initiated in 7 days post-hatch (dph) larvae weighing 23 mg (mean weight of 50 alive larvae). All the fish were considered as experimental and, due to the status of the species, we had to save as many fish as possible.

Rearing conditions

Tanks and water

Grey fibreglass troughs (1.00 x 0.5 x 0.15 m) were supplied with running, degassed and re-aerated (through col-

umns filled with plastic units) well water ($17.5 \pm 0.2^\circ\text{C}$). Some trials were carried out at $21 \pm 0.4^\circ\text{C}$ using water supplied from a recirculating system that included mechanical filtration, heating, UV, oxygen enrichment systems and a daily water renewal of 10%. For both temperatures, flow-rates were adjusted to maintain a minimum oxygen outlet level of around 7 mg l⁻¹.

Food and management

Four different food items were tested at first feeding. One-day old *Artemia salina* nauplii or chironomids were offered as live food. Two types of commercial compound diets were offered, already proven to be efficient with *A. baerii* and *A. ruthenus* larvae: the smallest size of Lanzi R1 (80-200 mm), from Artemia System SA (now INVE, Ghent, Belgium) with the following composition: 58% protein, 14% lipid, 12% ash, 7% moisture, vitamins A, D3, E and C; and the Inra formula, 80-120 mm pellet diameter, from NACIP, Montpellier, France, with the following composition: 50% protein, 10% lipid, 6% ash, 4% moisture, vitamins A, D3, E and C.

Refusals and faeces were removed twice a day. Dead larvae were removed and counted daily for every experiment. 30 larvae were taken weekly for average live weight determination. A monthly bacterial survey was carried out on the larvae during the first four months.

Design for feeding experiments

A synthesis of experiments is presented in table I.

Table I. - Main characteristics of the four experiments on larval and fingerlings rearing *Acipenser sturio* in 1995. See text for more details. [Principales caractéristiques des quatre expérimentations d'élevage de larves et d'alevins d'*Acipenser sturio* en 1995. Voir le texte pour plus de détails.]

Experiment	Objective	Rearing conditions				Age of fish at start (dph ¹)
		Temperature (°C)	Duration (days)	Fish numbers per trough (mean weight at start)	Replicate	
Experiment 1 ²	First food feeding (2 compound diets and 2 live prey)	17.5 and 21 ³	30 days ⁴	1,500 (23 mg)	2	7 dph
Experiment 2	Weaning on compound diet ⁵ : Age at weaning	17.5	8 weeks (a new trial is initiated each week)	200 (first 6) and 100 (last 2) (51 to 1520 mg)	no	22 dph to 71 dph ⁷
	Type of weaning (short and long ⁶)	17.5	56 days	200 (460 and 639 mg)	no	50 dph ⁷
Experiment 3	Influence of enrichment of nauplii <i>Artemia salina</i>	17.5	20 days	100 (135 and 148 mg)	no	49 dph ⁷
Experiment 4	Fresh and frozen chironomids	17.5	40 days	100 (660 mg)	no	51 dph

¹ dph = days post hatching.

² An additional trough, not included in the experiment, supplied with river water contained 1,500 larvae.

³ Due to limited number of larvae, batch of larvae fed *Artemia salina* nauplii at 21°C was omitted.

⁴ As nauplii were observed in digestive tract at 16 dph, nauplii were delivered to all batches as a precaution.

⁵ A pool of the two compound diets was delivered.

⁶ Weaning: short in 3 days and long in 3 weeks.

⁷ Fish came from batches fed live food items in experiment 1.

Experiment 1

Comparison of first food acceptance using the 4 different food items mentioned above at two temperatures (17.5°C and 21°C). There were two replicates with 1,500 larvae in each, except in the case of nauplii where there was only one trough, supplied with 17.5°C water. Nauplii were distributed 4 times a day at a daily rate of 40 g/1,500 larvae. Chironomids were distributed 6 times a day at a daily rate of 30 g/1,500 larvae. Compound diets were distributed every two hours (during working hours, 8.00–18.00) and offered *ad libitum* (10–15% body weight per day). First feeding and expulsion of the melanine plug were checked. The melanine plug corresponds “to the accumulation of granules of the embryonic development in the digestive tube lumen” (Dettlaff *et al.*, 1993). Depending on sturgeon species, expulsion of the melanine plug either precedes (*Acipenser transmontanus*: Monaco *et al.*, 1981; *Acipenser gueldenstaedtii*: Dettlaff *et al.*, 1993) or follows first feeding (*Acipenser baerii*: Gisbert and Williot., 1997).

The fish used in experiments 2, 3 and 4 were from batches which had been fed live food items in experiment 1.

Experiment 2

Comparison of weaning methods depending on age of larvae and length of weaning at 17.5°C. The influence of age was examined by starting a new experimental batch each week ($n = 8$) with larvae fed natural food items. 200 larvae were used until the sixth weaning and 100 larvae for the final two weanings to conserve specimens. Experimental fish were aged from 22 dph to 71 dph at the beginning of trials. A short weaning period (3 days) was applied. At start larvae were offered live food *ad libitum* (*Artemia salina* nauplii and chironomids for the younger and only chironomids from 38 dph onwards). After completion of weaning larvae were fed a mix of equal quantities of the two compound diets *ad libitum* (10–15% body weight per day). Short (3 days) and long (3 weeks) weaning periods, i.e., a progressive switch to a compound diet, were compared using two batches of 200 larvae at 50 dph.

Experiment 3

Effect of enriching nauplii with a commercial product at 49 dph (135–148 mg; not significantly different, U-test, $p = 0.5$). The smallest fish were used for this experiment as a potential aid to better growth. Nauplii were enriched (Super Selco, INVE, Belgium) for an additional day before being offered to larvae at a daily rate of 80 g/trough. The control consisted of distributing non-enriched nauplii to batches of 100 larvae. This experiment was performed for three weeks at 17.5°C.

Experiment 4

Comparison of live and frozen chironomids in a 40-day

experiment at 17.5°C. One hundred larvae (51 dph and 0.65 g on average) were used for control and treatment batches. They were fed 4 times a day at a daily rate of 50 g/trough.

Stocking

The marking procedure was tested using *A. ruthenus* fingerlings as a biological model. A solution of oxytetracycline chlorydrate (OTC) (7.5 g.l⁻¹) buffered at pH 7.5 oxygen enriched was applied in an 8-minute bath (Brun *et al.*, 1998). Traces of OTC were detected by microscopic observation ($\times 63$) of sections of prepared first pectoral fin ray with UV filter. Prior to final handling, the fingerlings were starved for 24 h. They were transported in plastic bags one fifth filled with water, then inflated with oxygen. Release locations were downstream from potential spawning grounds in zones known for their richness in benthos; according to advice from water bailiffs. The bags were not opened immediately to allow time for temperatures to equilibrate. Hatchlings were unloaded *via* a pipe sunk deep into the water column to avoid rapid drift due to surface current.

Statistical treatment

Two-way ANOVA was used to analyse the effects of food items and water temperature on weight in experiment 1 and one-way ANOVA was used to analyse the effects of food items on weight for a given temperature, with the Holm-Sidak method to estimate all pair-wise comparisons when needed. One-way ANOVA (Kruskal-Wallis, KW) and further Dun's test were used to compare the weight at 20-d and 34-d post initiation of weaning to that at initiation of weaning. Chi-square (χ^2) and z-test were used to compare series of percentages and two proportions respectively. The significance level retained was $p < 0.05$. Normality was tested using the Kolmogorov-Smirnov (KS) test. Depending on normality, either a *t*-test or a U-test was used to compare two sets of weights (Sigmastat, 1995).

RESULTS

Experiment 1

The first excretion of the melanin plug occurred at 12 days post hatching (dph). Nauplii were observed in the digestive tract for the first time at 16 dph at a mean weight of 31 mg. From that age all four batches received nauplii in addition to their corresponding food item in order to optimise survival (i.e., to reduce mortality due to potential refusal of other food). First faeces were observed at 19 dph. Weights recorded in the batch reared at 17.5°C and fed on nauplii were higher at 16 and 23 dph than any other batch (Tab. II). At day 30, growth was better at 21°C compared with 17.5°C, and for a given temperature there were no dif-

Table II. - Growth of *A. sturio* larvae according to age, food items and water temperature. Data are weight (mg) as mean \pm sd or median (25% - 75% percentiles) for normally and non-normally distributed data respectively. [experiment 1]. 1: Characteristics of larvae when experiment initiated. 2: The same superscript letter denotes the absence of statistical difference at $p = 0.05$. [*Croissance des larves de A. sturio selon leur âge, le type d'aliment et la température de l'eau. Les données correspondent au poids (mg) et sont représentées par la moyenne \pm écart type ou par la médiane (25%-75% centiles) selon que les données sont distribuées normalement ou non [expérience 1]. 1 : Caractéristiques des larves au début de l'expérience. 2 : La même lettre en exposant indique l'absence de différence statistique à $p = 0,05$.]*

Age (dph)	Temperature (°C)	Live food		Compound diet	
		1-day old nauplii	Chironomids	Inra	Lanzy
7 ¹	17.5 and 21	23			
16 ²	17.5 21	30.7 \pm 4.1 ^a	27 (26 - 29) ^b 27.5 (26 - 31) ^b	27 (25 - 28) ^b 25 (23 - 26.5) ^b	25 (24 - 27) ^b 24 (23 - 26) ^b
23	17.5 21	59.1 \pm 17 ^a	53.5 \pm 15.5 ^b 53.3 \pm 16.1 ^b	48.9 \pm 13 ^b 52.9 \pm 17.4 ^b	44.6 \pm 12.6 ^c 47.7 \pm 14.5 ^c
30	17.5 21	80 (58 - 111) ^a	70 (52 - 99.5) ^a 104.3 \pm 44 ^b	82.9 \pm 31.9 ^a 91.5 \pm 31.2 ^b	81.8 \pm 33.5 ^a 94.6 \pm 29 ^b
37	17.5 21	151.4 \pm 67.5 ^{ab}	155.6 \pm 57.1 ^{ab} 174.9 \pm 80.7 ^{ab}	174.4 \pm 65.7 ^a 171.8 \pm 71.9 ^{ab}	141.4 \pm 59.8 ^b 163.2 \pm 80.6 ^{ab}

Table III. - Cumulated mortality (%) in *A. sturio* larvae depending on age, food items and water temperature. Age of larvae at start was 7 dph. [experiment 1]. * The same superscript letter denotes the absence of statistical difference at $p = 0.05$. [*Mortalité cumulée (%) chez les larves de A. sturio selon l'âge, le type d'aliment nourriture et la température de l'eau. L'âge des larves au début de l'expérience est de 7 jae. [expérience 1]. * La même lettre en exposant indique l'absence de différence statistique à $p = 0,05$.]*

Age (dph)	Temperature (°C)	Live food		Compound diet	
		1-day old nauplii	Chironomids	Inra	Lanzy
16*	17.5 21	13.2 ^d	3.8 ^a 8.4 ^b	8 ^b 10.9 ^c	8.8 ^b 11.8 ^c
23	17.5 21	22.3 ^a	21.3 ^a 38.8 ^d	22.6 ^a 33.3 ^c	28 ^b 37.2 ^d
30	17.5 21	26.4 ^a	28.6 ^a 44.9 ^d	27.6 ^a 40.4 ^c	34.2 ^b 45.3 ^d
37	17.5 21	29.7 ^a	31.1 ^a 49.7 ^c	29.5 ^a 47.1 ^c	35.7 ^b 49.2 ^c

ferences with regard to the food. At the end of the experiment (37 dph) there were no significant differences in mean weight except that weights recorded for fish fed on Inra formula were significantly higher than for those fed on Lanzy. It is worth noting that the range of variation within all batches is very wide, with the variation coefficient (sd/mean) sometimes reaching 50%. Mortality was very quickly higher at 21°C than at 17.5°C (Tab. III). From 23 dph to 37 dph mortality at 17.5°C was similar whatever the food item, with the exception of Lanzy where mortality was higher. At the end of the experiment mortality reached about 30% at 17.5°C and about 48% at 21°C. Maximum instantaneous daily biomass in the 21°C recirculating system was 180 g.

From the end of the experiment (38 dph), all batches were fed chironomids until any further experiments were carried out.

Experiment 2

Growth of short-weaned fish of different ages at the initiation of weaning at 17.5°C is shown in figure 1. Median weight recorded 20 days post weaning (dpw) was significantly higher than that of the control larvae when weaning started at 22, 29, 36, 57 and 63 dph. At 34 dpw, median weight exhibited a dramatic increase. Final median weight for 34 dpw fish was close to 4,500 mg (only two specimens) compared with 1,800-1,300 mg for 20 dpw and control respectively. Survival patterns are shown in figure 2. They look similar with a very poor final survival rate, ranging from 0 to about 18%, except for weaning number 6, which exhibited survival close to 30%. This corresponded to 55-day old larvae when weaning was initiated. This pattern was confirmed in figure

3 where cumulative survivals were plotted 20 and 34 days post weaning initiation. In the latter case, most (90%) of mortalities occurred. Whatever the delay after the initiation of weaning, the best significant survival was recorded for 55 dph larvae (700 mg, mean weight). Both younger and older weaned fish had poorer survival rates.

Long term weaning (3 weeks) resulted in greater ($p = 0.01$) larval weights after 56 days than for larvae weaned over a shorter period (3 days), 6.39 g vs 2.93 g (median weight) respectively (Fig. 4). Mortality patterns were similar but the mortality peak for short weaning

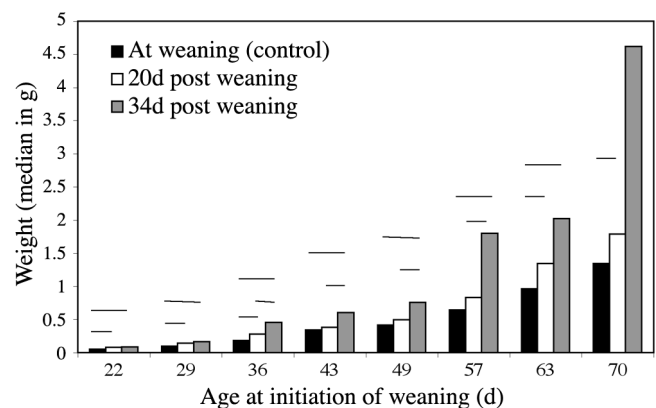


Figure 1. - Growth of *A. sturio* larvae according to age when weaned on compound diet (median weight determined 20 and 34 days post weaning initiation; short weaning (3 days) at 17.5°C). Horizontal bars link the batches exhibiting significant differences ($p < 0.05$; KW ANOVA). [*Croissance des larves de A. sturio selon leur âge au sevrage sur aliment composé (poids moyen déterminé 20 et 34 jours après le début du sevrage ; sevrage court (3 jours) à 17,5°C). Les barres horizontales relient les lots présentant des différences significatives ($p < 0,05$; KW ANOVA).]*

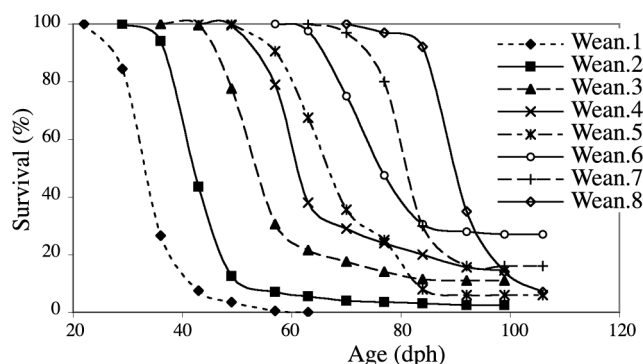


Figure 2. - Survival of *A. sturio* larvae according to age when weaned on compound diet, short weaning (3 days) at 17.5°C. [Survie de larves de *A. sturio* selon leur âge au sevrage sur aliment composé, sevrage court à 17,5°C.]

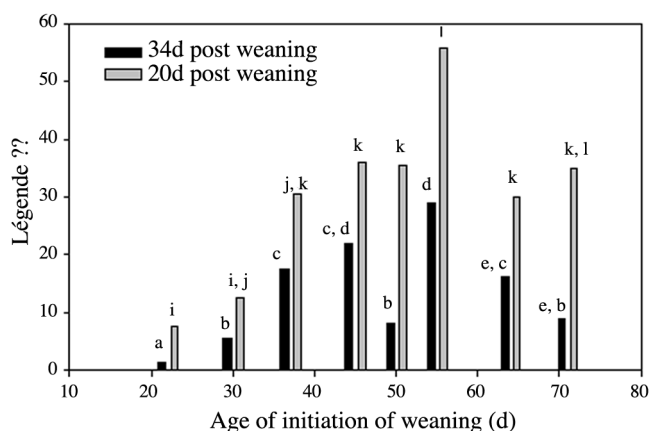


Figure 3. - Cumulative survival of *A. sturio* larvae according to age at initiation of weaning on compound diet (survival determined 20 and 34 days post weaning initiation; short weaning (3 days) at 17.5°C). Same letter denotes the absence of significant difference. [Survie de larves de *A. sturio* selon leur âge au début du sevrage sur aliment composé (survie déterminée 20 et 34 jours après le début du sevrage ; sevrage court (3 jours) à 17,5°C). La même lettre traduit l'absence de différence significative.]

occurred 2 weeks earlier than for long weaning (Fig. 5). Mortality rates were greater ($p < 0.001$; z-test) for short weaning compared with long weaning, 94 and 68.5% respectively.

Experiment 3

Enriched *A. salina* nauplii-fed larvae weighed 700 mg - not significantly higher than the control (640 mg). Mortality was similar, 8.5 and 6% respectively.

Experiment 4

Fingerlings fed live and frozen chironomids exhibited very similar final weights (2.88 g and 2.87 g) and mortality (1 and 1.5% respectively). This meant that we were able to feed frozen chironomids to the remaining fingerlings destined to be stocked.

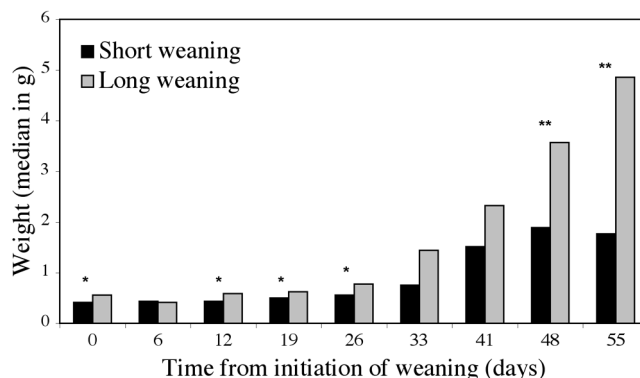


Figure 4. - Growth (median weight) of *A. sturio* larvae according to length of weaning (short (3 days) and long (3 weeks)). At initiation of weaning on compound diets at 17.5°C, larvae were 50-days post hatch. (* = $p < 0.05$; ** = $p < 0.01$; U test). [Croissance (médiane du poids) de larves de *A. sturio* selon la longueur du sevrage (court (3 jours) et long (3 semaines)). Au moment du sevrage sur aliment composé à 17,5°C, les larves étaient âgées de 50 jours. (* = $p < 0,05$; ** = $p < 0,01$; test U).]

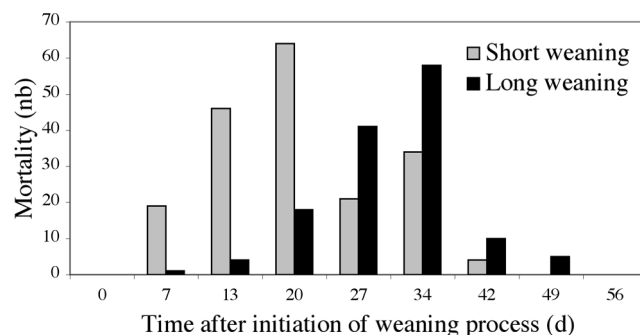


Figure 5. - Mortality distribution (number of individuals) in *A. sturio* according to length of weaning (short (3 days) and long (3 weeks)). At initiation of weaning on compound diets at 17.5°C, 200 larvae were 50-days post hatch. [Distribution des mortalités (nombre d'individus) chez *A. sturio* selon la longueur du sevrage (court (3 jours) et long (3 semaines)). Au début du sevrage sur aliment composé à 17,5°C, 200 larves avaient 50 jours.]

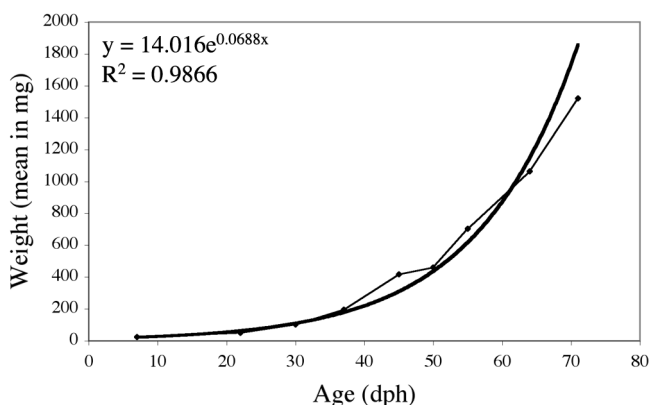


Figure 6. - Growth of *A. sturio* larvae fed *Artemia salina* nauplii then chironomids at 17.5°C. [Croissance de larves de *A. sturio* nourries avec des nauplii d'*Artemia salina* puis de chironomes à 17,5°C.]

A growth curve was plotted for batches fed live prey till 70 dph at 17.5°C (Fig. 6).

Rearing for stocking and further experiment

Three non-specific bacteria were detected during the first four-month rearing period. They were *Aeromonas sobria*, which can give rise to septicaemia, *Lactococcus lactis* and *Flexibacter columnaris*, which leads to necrosis. The second bacterium was most probably introduced by chironomids as worms are often carriers of this germ. The last germ was treated with an oxytetracyclin (20 mg l⁻¹) bath for 60 minutes.

Three different batches of fish were stocked in 1995. Altogether 2,000 hatchlings (~20 mg) were released in June, 5,000 (~1 g) marked fingerlings in August, and 2,000 (~6.5 g) marked fingerlings in October. The few fingerlings that were successfully weaned on compound diets (~200) as well as a batch (~120) of fingerlings fed on frozen chironomids were kept for further growing and broodstock experiments. In 1996, 40 small juveniles were sent to Germany (Institute of Freshwater Ecology and Inland Fisheries in Berlin) as part of a cooperation programme for the preservation of the species.

DISCUSSION

This is the first time that larval feeding of the critically endangered European Atlantic sturgeon, *Acipenser sturio*, has been reported. The first food item observed in the digestive tract at 16 days post-hatch was *Artemia* nauplii. This exogenous feeding followed the expulsion of the melanin plug (12 days post-hatch), thus confirming that this expulsion was not the consequence of the first feeding as previously reported for *A. baerii* (Gisbert and Williot, 1997). For the same water temperature (17.5°C), first feeding of *A. sturio* occurred later than for *A. baerii* (9 days post-hatch) when fed compound diet (Gisbert and Williot, 1997). Most of the larvae were then fed a mix of natural and compound diets for 22 days (from 16 dph to 38 dph) and later chironomids. Batches fed nauplii from the beginning exhibited better growth and better survival than any other food item till 23 dph. This practice of delivering multi-food items, also called co-feeding, is usually applied as a progressive larval weaning on compound diets (Kolkovski, 2001). In this condition of multi delivery food items, survival of *A. sturio* larvae at 38 days post-hatch ranged from 50 to 70%. This is lower than survival recorded for other species of sturgeon larvae fed a single food item at similar or higher temperatures: *Acipenser oxyrinchus* (> 87%) (Mohler, 2000), *A. baerii* (ca.

80%) (Gisbert & Williot, 1997), and *Acipenser transmontanus* (> 94%) (Deng *et al.*, 2003). It is noteworthy that these last two species were weaned directly on compound diets. In the present work, short weaning at 17.5°C exhibited the best survival of 30% recorded 34 days post initiation of weaning for 55 days post hatch-weaned. This bell shaped survival curve is uncommon. In addition to weaning successes reported in *A. baerii* and *A. transmontanus*, Mohler (2000) mentioned a survival > 75% post direct weaning for 26-day old *A. oxyrinchus*. This reinforces the unusual findings for *A. sturio*. Long weaning (3 weeks) considerably increased growth compared with short weaning (3 days), the later the weaning the better the growth. Long weaning also improved survival rates. This suggests that a long adaptation is needed to properly convert to a compound diet. Present findings, the bell shaped survival curve, might be due to differences in ontogenetic development of the digestive structure as shown in *A. baerii* (Gisbert *et al.*, 1999). The delayed effects on survival might be due to the absence of components in the food mix (e.g. dietary enzyme or other components: vitamins, amino acids, lipid fractions) involved in food absorption and assimilation, as mentioned in teleosts (Cahu and Zambonino Infante, 2001; Kolkovski, 2001; Takeuchi, 2001). Survival may be influenced by rearing density, as reported for *A. oxyrinchus* (Mohler, 2000).

Enrichment with *Artemia* nauplii did not bring any improvement in growth or survival during the three weeks experimental period. Nevertheless, this procedure most probably allowed recovery for some very small experimental fish and the method is highly recommended for many marine fish larvae (Cahu and Zambonino Infante, 2001; Shields, 2001; Sorgeloos *et al.*, 2001; Takeuchi, 2001). Since the availability of *Artemia* has declined recently (Sorgeloos *et al.*, 2001), investigation into compound diets should be promoted. Live and frozen chironomids did not lead to any differences in growth or survival of fingerlings between 0.6 g and 2.9 g. This allowed us to feed fingerlings at a lower cost.

The present findings on *A. sturio* larval rearing suggest biological traits specific to this species compared with other sturgeon species. However, similar work should be re-investigated with larvae from good quality gametes to determine whether or not present findings were dependent on the origin of the larvae, the number of replicates should be increased and growth rates might be helpful to discriminate different treatments.

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REFERENCES

- BRUN R., PELARD M. & P. WILLIOT, 1998. - Utilisation de deux méthodes pour marquer les cohortes d'esturgeons. In: Fisheries Management of the Danube River Basin (Rauta M., Bacalbasa-Dobrovici N., Vasilescu G. & L. Oprea, eds), pp. 56-57. Braila, Romania: Tipografia CEPROHART.
- CAHU C. & J. ZAMBONINO INFANTE, 2001. - Substitution of live food by formulated diets in marine fish larvae. *Aquaculture*, 200: 161-180.
- DENG DONG-FANG, KOSHIO S., YOKOYAMA S., BAI S.C., QINGJUN SHAO, YBO CUI & S.S.O. HUNG, 2003. - Effects of feeding rate on growth performance of white sturgeon (*Acipenser transmontanus*) larvae. *Aquaculture*, 217: 589-598.
- GISBERT E. & P. WILLIOT, 1997. - Larval behaviour and effect of timing of initial feeding on growth and survival of Siberian sturgeon (*Acipenser baerii*) larvae under small scale hatchery production. *Aquaculture*, 156: 63-76.
- GISBERT E., SARASQUETTE M.C., WILLIOT P. & F. CASTELLO-ORVAY, 1999. - Histochemistry of the development of the digestive system of Siberian sturgeon during early ontogeny. *J. Fish Biol.*, 55: 596-616.
- KOLKOVSKI S., 2001. - Digestive enzymes in fish larvae and juveniles-implications and applications to formulated diets. *Aquaculture*, 200: 181-201.
- LEPAGE M. & E. ROCHARD, 1995. - Threatened fishes of the world: *Acipenser sturio* Linnaeus, 1758 (Acipenseridae). *Environ. Biol. Fish.*, 43: 28.
- MOHLER J.W., 2000. - Early culture of the American Atlantic sturgeon *Acipenser oxyrinchus* Mitchill, 1815 and preliminary stocking trials. *Bol. Inst. Esp. Oceanogr.*, 16: 203-208.
- MONACO G., BUDDINGTON R.K. & S.I. DOROSHOV, 1981. - Growth of white sturgeon (*Acipenser transmontanus*) under hatchery conditions. *J. World Maricult. Soc.*, 12: 113-121.
- SHIELDS R.J., 2001. - Larviculture of marine finfish in Europe. *Aquaculture*, 200: 55-88.
- SIGMASTAT, 1995. - User's manual, version 2.0 for windows 95, NT & 3.1. Jandel scientific software.
- SORGELOOS P., DHERT P. & P. CANDREVA, 2001. - Use of the brine shrimp, *Artemia* spp., in marine fish larviculture. *Aquaculture*, 200: 147-159.
- TAKEUCHI T., 2001. - A review of feed development for early life stages of marine finfish in Japan. *Aquaculture*, 200: 203-222.
- TROUVERY M., WILLIOT P. & G. CASTELNAUD, 1984. - Biologie et écologie d'*Acipenser sturio* : étude de la pêche. 79 p. Série esturgeon n° 1, Étude Cemagref, Groupement de Bordeaux.
- WILLIOT P., ROCHARD E., CASTELNAUD G., ROUAULT T., BRUN R., LEPAGE M. & P. ÉLIE, 1997. - Biological characteristics of European Atlantic sturgeon, *Acipenser sturio*, as a basis for a restoration program in France. *Environ. Biol. Fish.*, 48: 359-370.
- WILLIOT P., BRUN R., PELARD M. & D. MERCIER, 2000. - Induced maturation and spawning in an incidentally caught adult pair of critically endangered European sturgeon, *Acipenser sturio* L. *J. Appl. Ichthyol.*, 16: 279-281.
- WILLIOT P., ROUAULT T., BRUN R., PELARD M. & D. MERCIER, 2002. - Status of caught wild spawners and propagation of the endangered sturgeon *Acipenser sturio* in France: A synthesis. *Intern. Rev. Hydrobiol.*, 87: 515-524.

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